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(71) Applicant
Festo KG

(Incorporated in the Federal Republic of Germany)

Ruiter Strasse 82, 7300 Esslingen,
Federal Republic of Germany

(72) Inventors
Kurt Stoll
Jürgen Arbter
Jürgen Gerhartz
Reinhard Schwenzer
Dieter Waller

(74) Agent and/or Address for Service
Swindell & Pearson
48 Friar Gate, Derby, DE1 1GY, United Kingdom

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(58) Field of search
UK CL (Edition K) H1P PAC PBA PMR
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(54) **Solenoid valves**

(57) The valve has at least one solenoid coil 18, 19 in which an armature 10 connected to a valve spool 13 is axially displaceable. The armature includes a permanent magnet 11 having pole pieces 12. The valve spool 13 is provided with flow controlling lands 14 for cooperation with parts 16 and magnetic field sensors 22, 23 connected to amplifiers 24, 25 detect the position of the armature. The valve may have one or two stable positions.

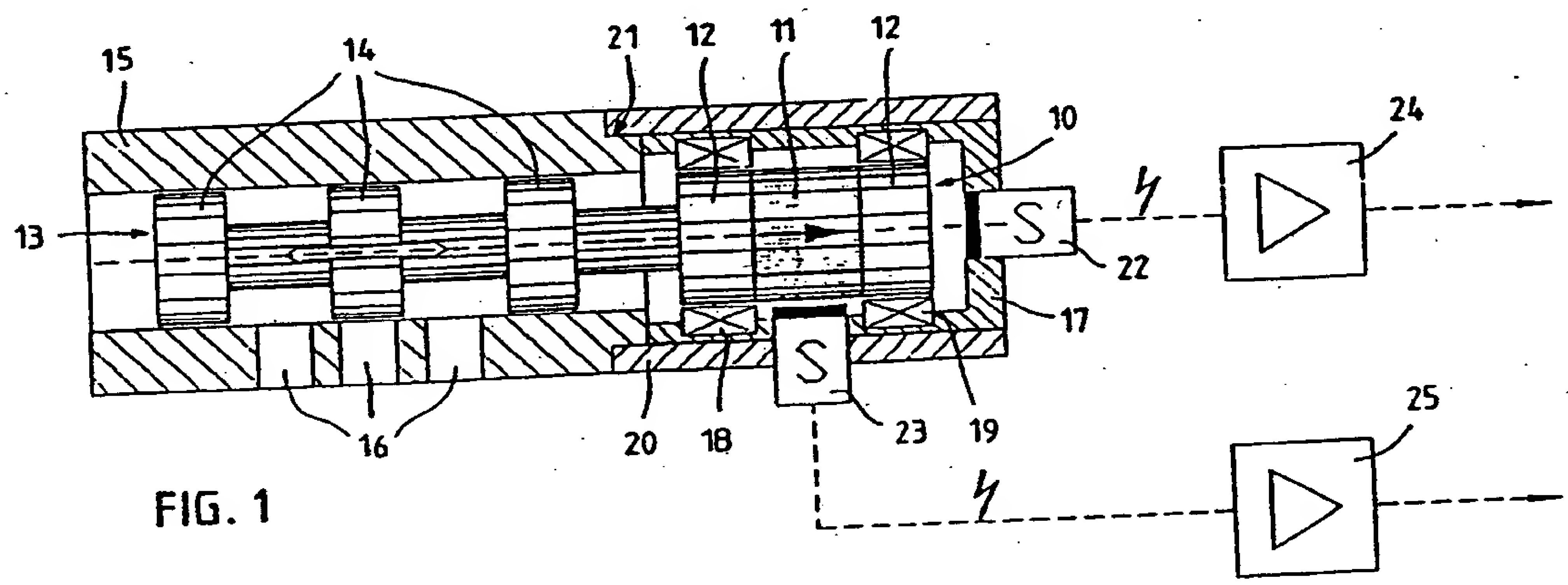

FIG. 1

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AH

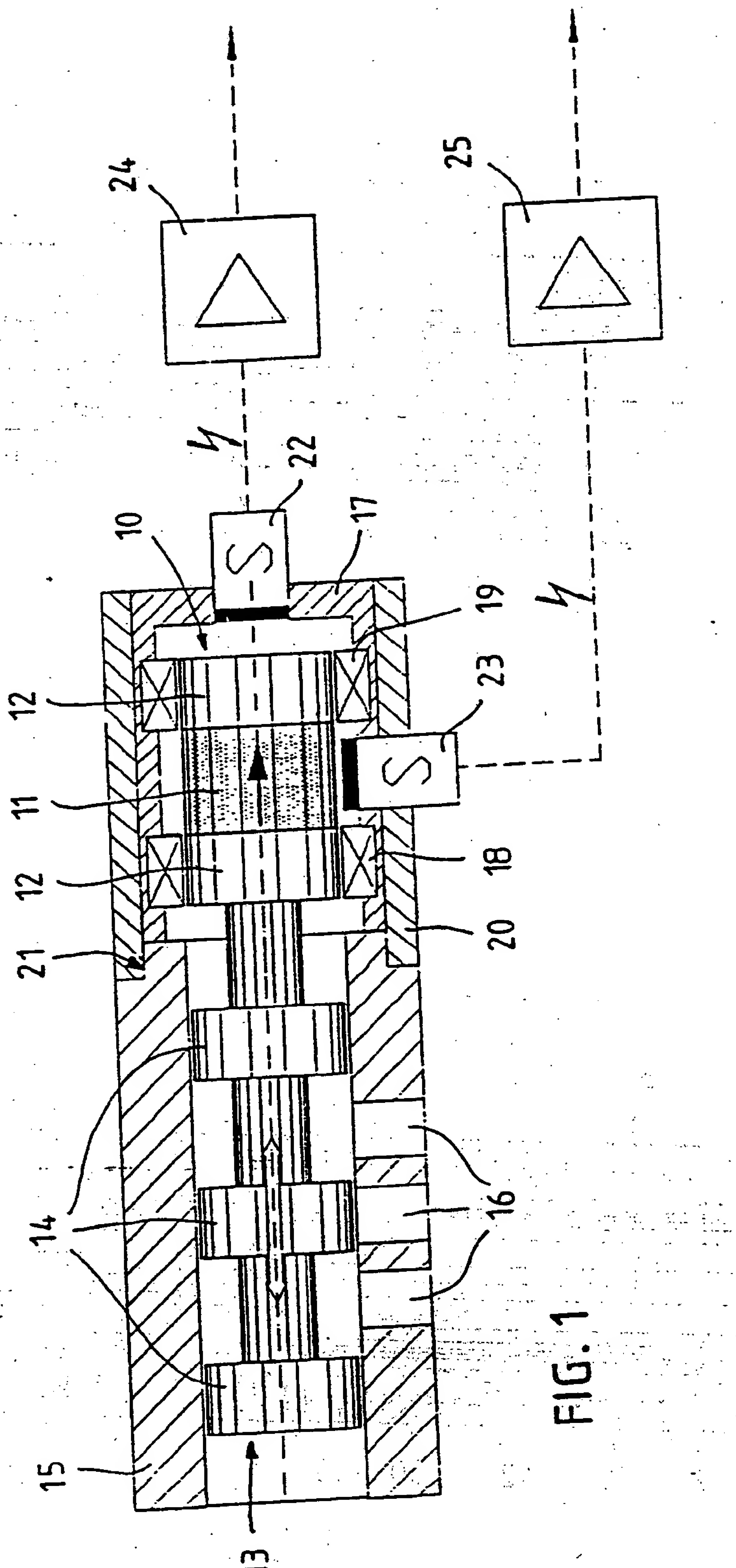

FIG. 1

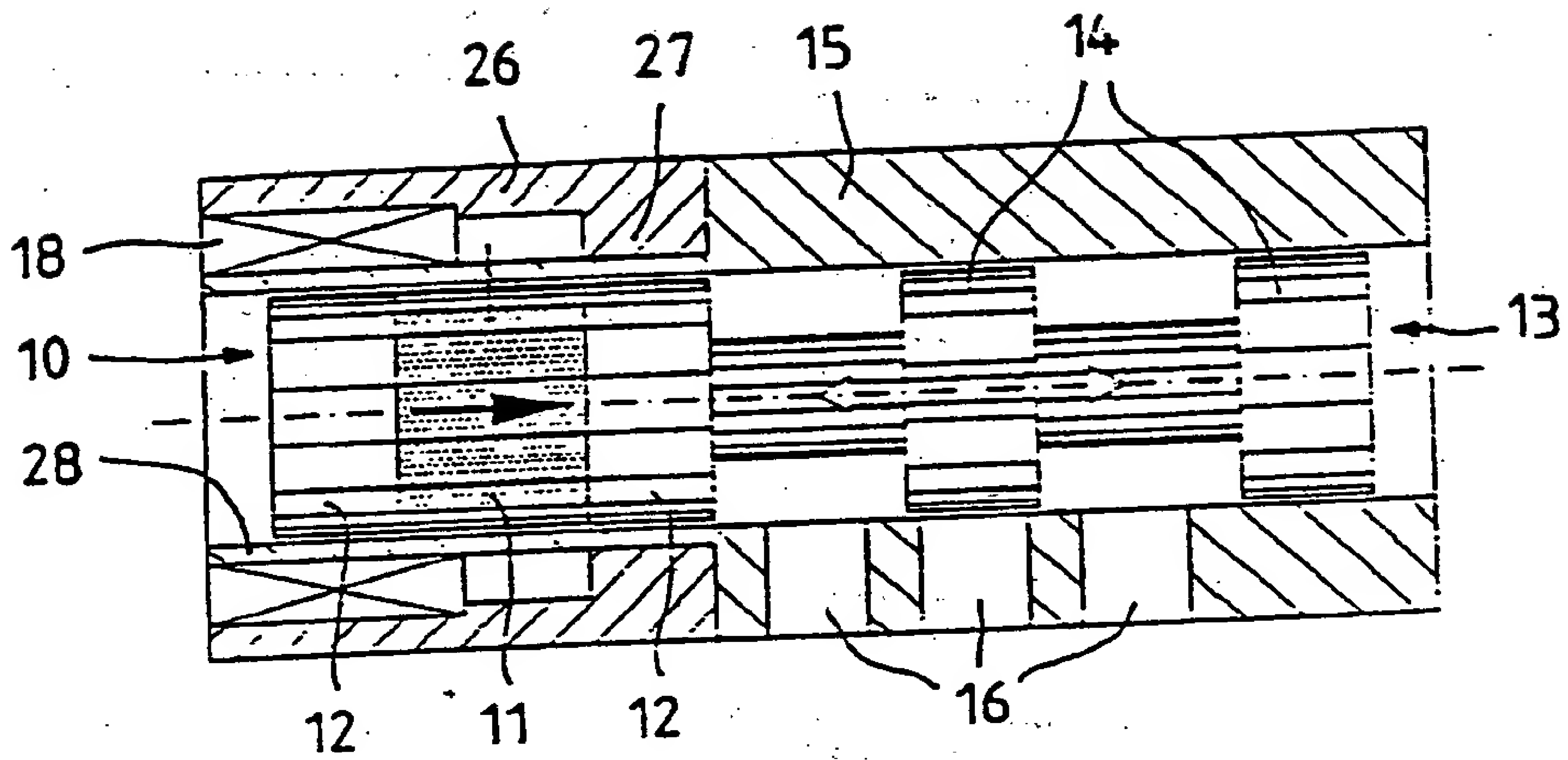
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FIG. 2

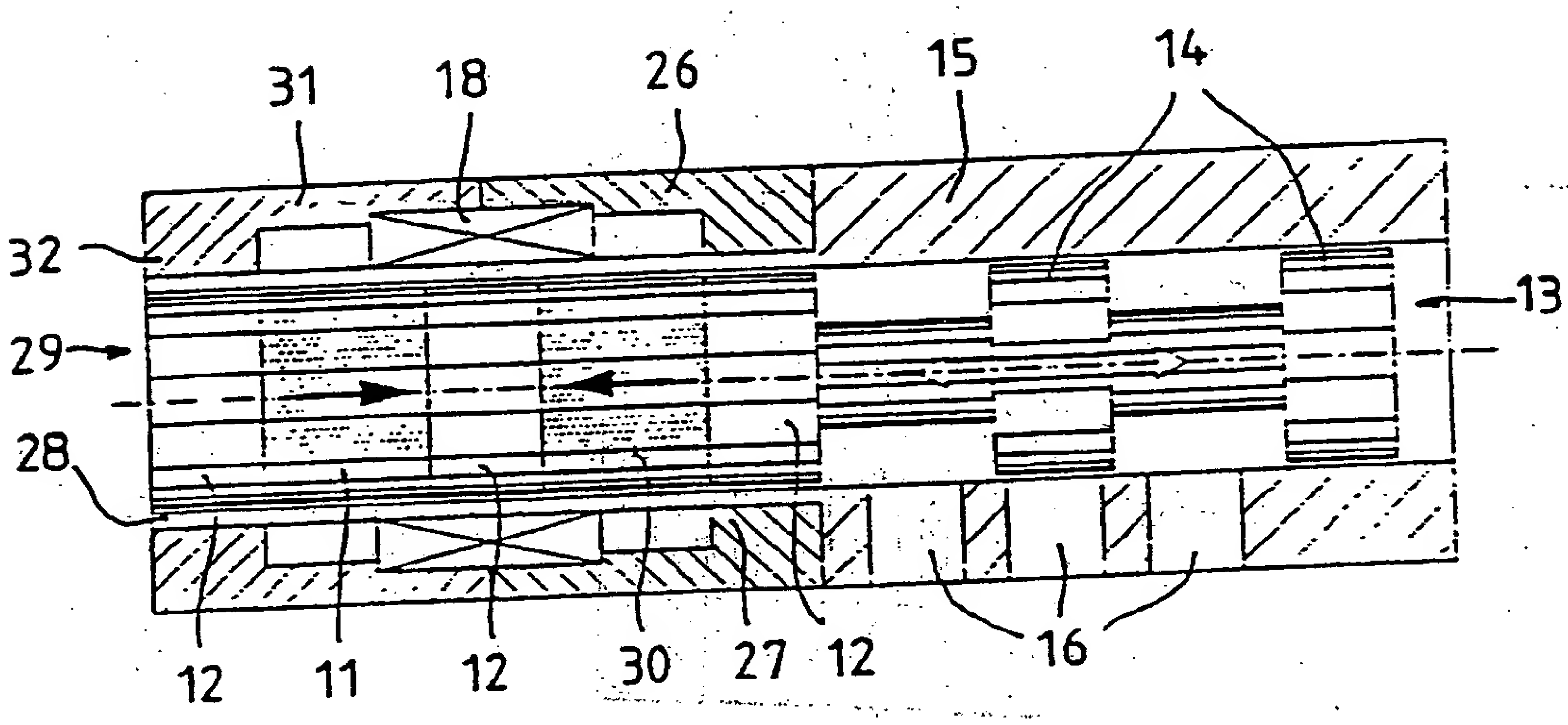
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FIG. 3

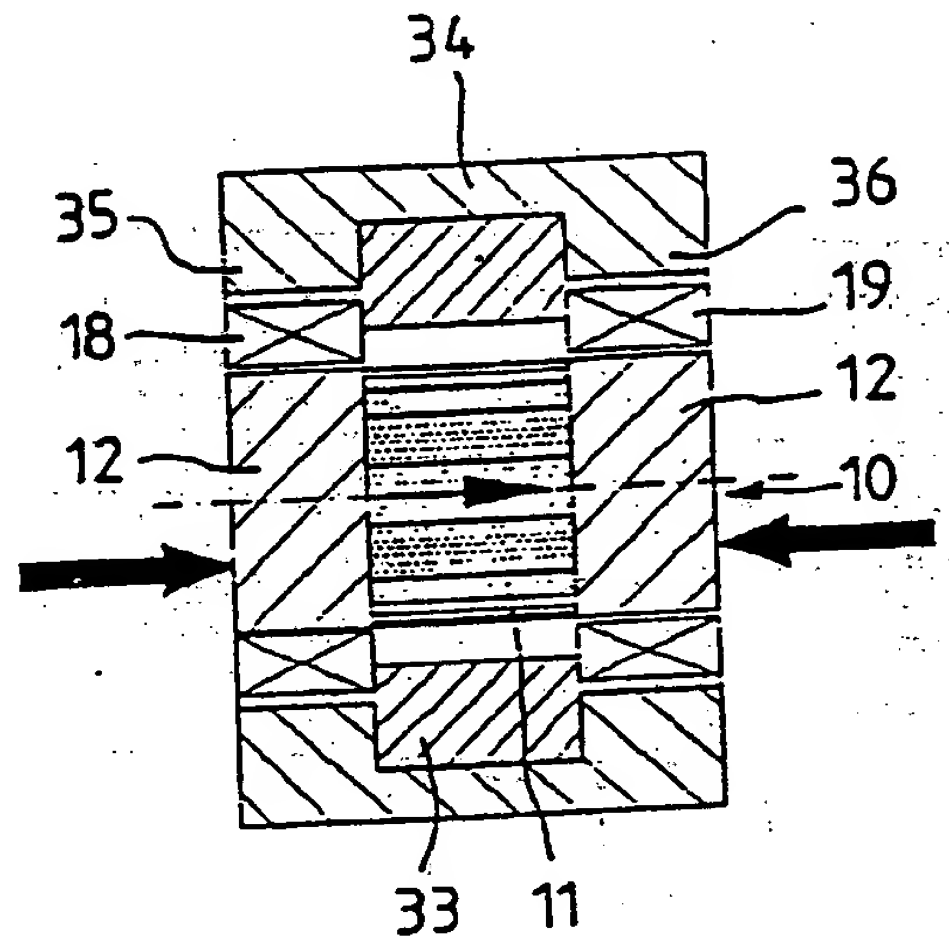

FIG. 4

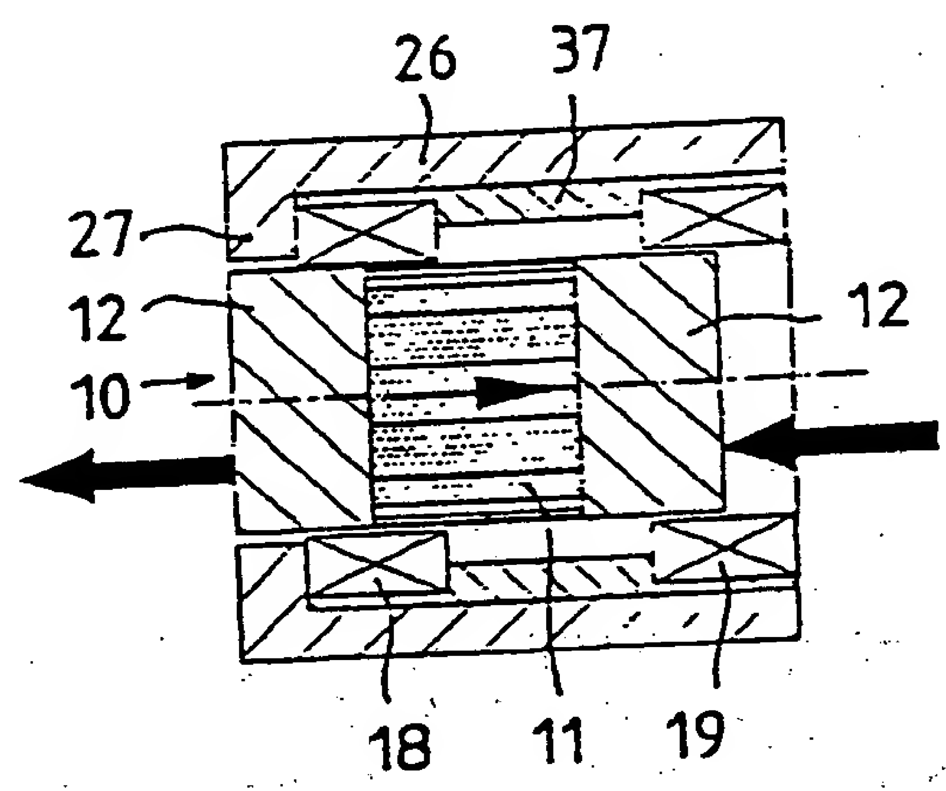

FIG. 5

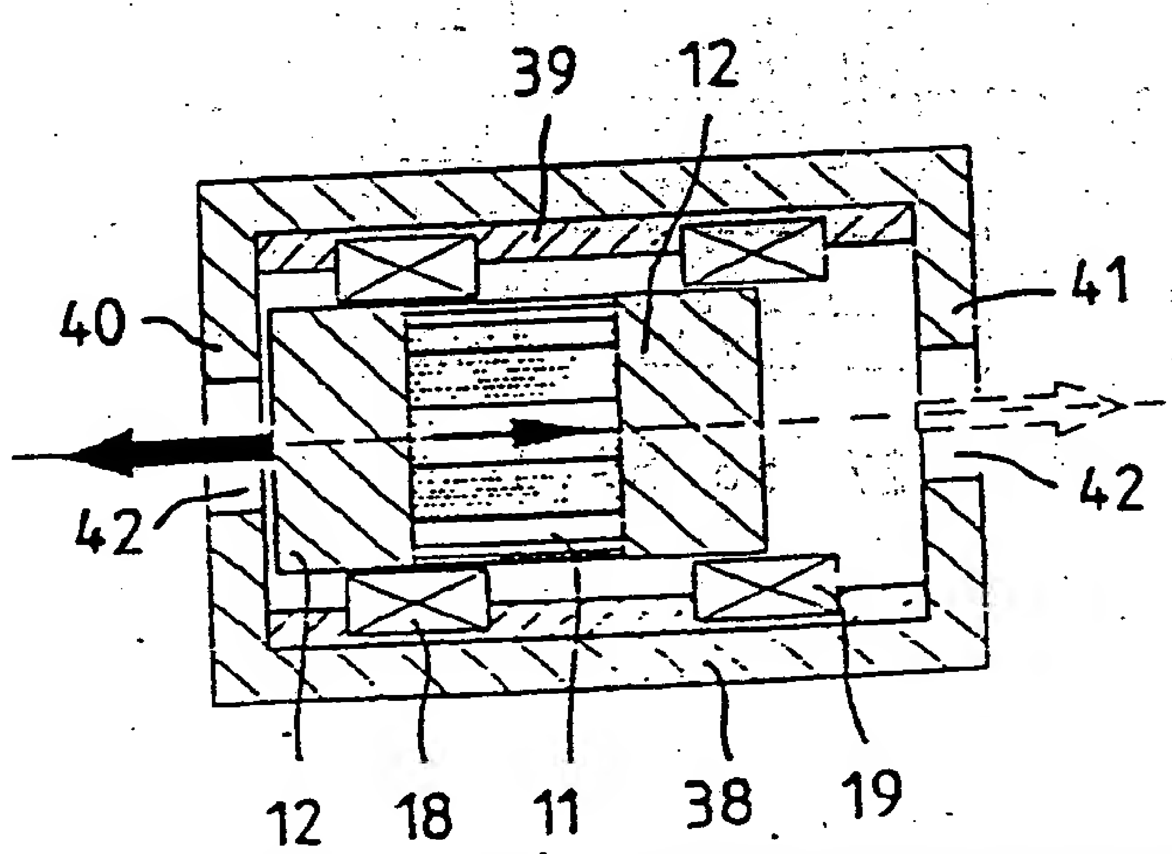

FIG. 6

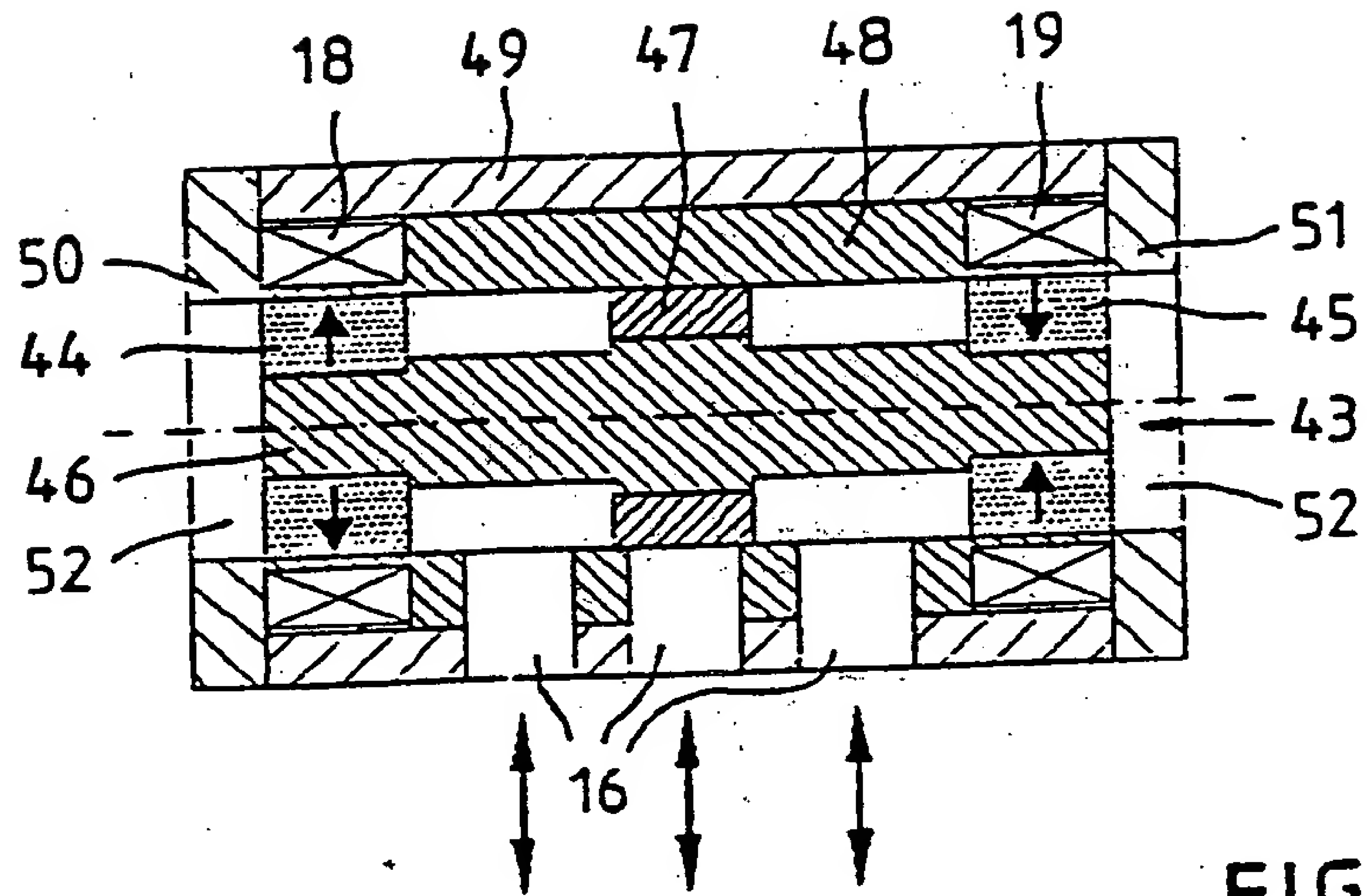
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FIG. 7

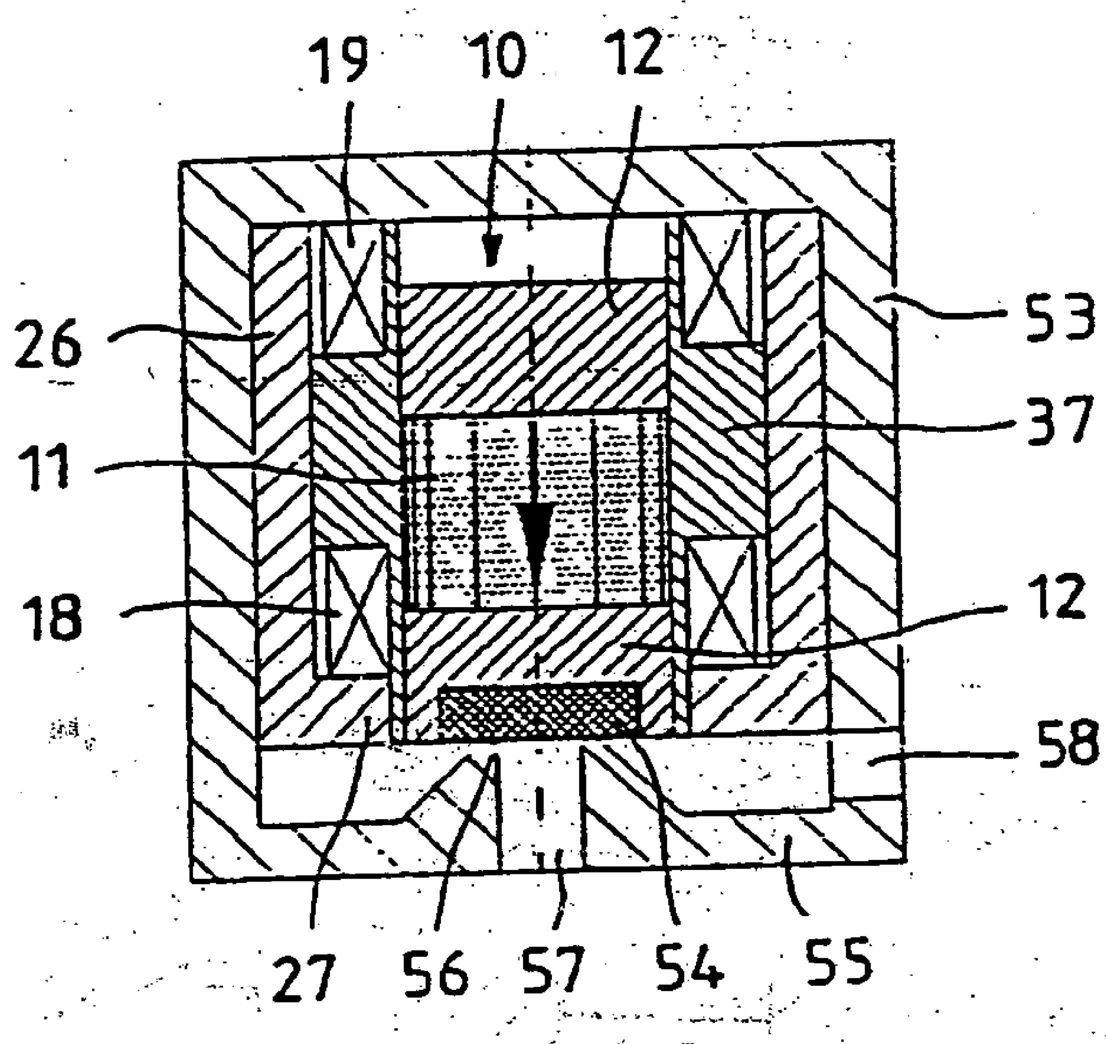
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FIG. 8

A Solenoid Valve.

The invention relates to a solenoid valve, and more particularly but not exclusively to such a valve with at least one solenoid coil, in which a magnet armature which is provided with a valve element, is guided so as to be able to move axially.

Such a solenoid valve is for instance described in the German patent publication 8,530,286 U or the German patent publication 3,034,817 A. The principle of operation of the known solenoid valve resides in that a ferromagnetic magnetic core is magnetized by current flowing in the solenoid coil in which it is positioned and magnetically attracts a sliding magnet armature, which after the switching off of the current is returned by the force of a spring into its original position. The force decreases with an increase in the distance between the magnet armature and the magnet core steeply so that the effective range of action is comparatively small.

In order to produce very rapid response of the armature, for instance in the case of loudspeaker systems, it is known to use a moving coil transducer, which makes use of the Biot-Savart effect or, respectively, Lorentz forces. In this respect an electrical coil is arranged to be moved in a bell magnet axially and has separate means for bearing it in order to make use of the displacing force, which is generally proportional to the current,

acting on the coil for driving a diaphragm. This system has also already been suggested for spool valves. The electrical power leads to the moving coil are however complex and liable to failure.

Accordingly one object of the invention is to so make use of the advantages of such known moving coil transducers, whose displacing force is approximately proportional to the current over the range of action, in such a manner for solenoid valves that there is a simple, low-cost design avoiding entrained power leads and large moving masses.

In order to achieve these or other aims, the invention provides a solenoid valve with at least one solenoid coil, in which a magnet armature, which is provided with a valve element, is guided so as to be able to move axially, and in which a moving armature system without a magnetic core is provided in the case of which the magnet armature is at least partly in the form of a permanent magnet.

In the case of the solenoid valve in accordance with the invention it is possible to ensure a displacement force which is practically proportional to the current and which is essentially constant over the entire stroke range. A magnet core as employed for conventional solenoid coils is not necessary, and this applies for the return spring also, since the magnet armature partly constituted by a permanent magnet may readily be positioned in its capacity of being a permanent magnet, it being moved out of this neutral position by excitation of the solenoid coil and automatically returned again by switching off the same. This leads to an extremely simple structure with only a few components which are practically free of wear. Furthermore, assembly is rendered very simple and cheap.

Further features of the invention are described in the claims.

The assembly of the structure may be facilitated by having a non-ferromagnetic armature housing, which bears the at least one solenoid coil and in which the magnet is slidingly arranged. In view of its function this magnet armature housing may also be termed a coil carrier.

In keeping with yet another particularly simple form of the invention the tubular magnet armature housing, which constitutes a sliding guide for the magnet armature, is in the form of the prolongation of a valve housing, in which the valve element which is rigidly connected with the magnet armature, is preferably slidingly guided. However, it is possible as well to do without any sliding guide means for the magnet armature, in which case the valve element, which is guided for sliding and axial movement in a valve housing, constitutes an axial guide means for the magnet armature rigidly connected with it. The valve housing may be connected with a magnet armature housing or it may be manufactured integrally with the same.

In order to improve the efficiency of the arrangement a ferromagnetic and essentially tubular iron circuit return member is provided, which externally fits around the magnet armature housing and the at least one solenoid coil. This iron circuit return member preferably has at least one inwardly directed annular projection, which in the current-free condition of the at least one solenoid coil is directed towards one terminal pole of the magnet armature and predetermines the neutral setting thereof. It is possible for the magnet armature to be moved out of this neutral setting by excitation of the magnet armature and to return into the latter owing to the force of the permanent magnetic field after switching off the solenoid coil automatically. There is the advantage that motion in either direction out of the neutral setting is possible in a way dependent on the direction of the current flow through the solenoid coil. The annular projection is in this case arranged outside the at least one solenoid coil.

In order to increase the effect of the force it is possible for the magnet armature to have two oppositely polarized permanently magnets which are arranged axially in series. two annular projections on either side of the solenoid coil respectively being directed towards the respectively outer terminal pole of the two permanent magnets. The result of this is that two separate magnetic circuits are formed, the solenoid coil respectively constituting the air gap for the magnetic circuits.

Both the displacing force and an also the retaining force are substantially higher in the neutral position in the case of this design.

It is possible to achieve a very compact arrangement of the solenoid valve if the valve housing accommodates the iron circuit return member and the magnet armature, if the magnet armature has a valve sealing member at one end surface at least, the valve housing has a valve seat resting on the valve sealing member in the current-free condition of the solenoid coil and the annular projection is directed towards the end part, which bears the valve sealing member, of the magnet armature. In the non-excited condition of the magnet armature the valve sealing member is hence in sealing engagement with the valve seat owing to the field force of the permanent magnet so that the valve may be opened by the flow of current in the solenoid coil. In lieu of a design with a normally closed valve it is however possible to have a design with a normally open one.

For some applications a design of the iron circuit return member as a housing has been found to be particularly advantageous, two annular projections then constituting the end sides of the housing. In the case of a design in the form of a bistable servo member two solenoid coils are arranged in this housing axially spaced out from each other. Then in the neutral position the magnet armature has two neutral positions, that is to say with engagement on the one end surface and engagement on the other end surface. In this case it is possible for the central openings constituted by the annular projections to be formed in the two end surfaces as valve openings.

In the case of further convenient design in which the iron return member in the form of a housing, the magnet armature is constituted by a valve switching spool, of which at least one flow controlling land is in the form of a permanent magnet. In this case it is possible to achieve very compact dimensions of the spool valve.

In order to increase the acting force it is possible furthermore to provide two flow controlling lands on the spool

member, which in the current-free condition of two solenoid coils are arranged underneath the same. These permanent magnets are in this case preferably made with an annular configuration.

It is possible to provide an extremely compact arrangement with an exactly centered magnet armature if two annular projections are directed towards two solenoid coils, the two end poles of the magnet armature being arranged underneath the latter in the current-free condition of the solenoid coils

In order to enhance the efficiency and to improve the positioning effect it is possible to provide an arrangement, in which the permanent magnet in the magnet armature has a cylindrical configuration and at both ends is provided with ferromagnetic pole pieces. These pole pieces cause an advantageous deflection of the magnetic flux from the end surface of the permanent magnet. In order to increase the servo force it is possible in this respect to provide a further oppositely polarized permanent magnet arranged in series and also having pole pieces.

An additional advantage of the solenoid valve in accordance with the invention is to be seen in the fact that the detection of the displacement of the magnet armature may be performed more particularly by an axial and/or radial magnetic field sensor which responds to the stray magnetic field. This means that it is possible to sense and to regulate the position of the magnet armature in an extremely simple way without the otherwise conventional mechanical functional elements.

The invention will now be described in more detail with reference to the accompanying drawings, which show several working embodiments thereof.

Figure 1 shows a first embodiment of the invention with two solenoid coils and with one valve spool rigidly connected with the magnet armature.

Figure 2 shows a second, similar working embodiment with only one solenoid coil.

Figure 3 shows a third, similar embodiment of

the invention with one solenoid coil and two permanent magnets in the magnet armature.

Figure 4 shows a fourth embodiment of the invention in the form of a compact automatically centered design with two solenoid coils.

Figure 5 shows a fifth, similar off-center design.

Figure 6 shows a sixth working embodiment having a bistable arrangement with two solenoid coils.

Figure 7 shows the seventh embodiment of the invention having a magnet armature in the form of a valve spool.

Figure 8 shows the eight embodiment of the invention with a magnet armature in the form of a normally closed valve member.

In the case of the working embodiment illustrated in figure 1 a magnet armature 10 consists of a circularly cylindrical permanent magnet 11, which at both ends has axially aligned pole pieces 12, which are also constituted by circularly cylindrical structures with the same diameter. The field of the permanent magnet 11 extends axially, as indicated by the arrow. The magnet armature 11 formed in this manner is rigidly connected with a valve flow controlling spool 13, which has three flow controlling lands 14 or collars.

The valve spool 13 is arranged in a valve housing 13 so that it may be axially shifted therein, the housing having three lateral connection ports 16. The design of the valve spool 13 and of the valve housing 13 is in principle such as to allow a wide range of variation and the present invention is not restricted to a particular form thereof. Thus it is possible to vary the number and the arrangement of the valve spools 13 and of the connection ports 16 practically without any restrictions.

The valve housing 15 is connected with a non-ferromagnetic magnet armature housing 17 fitted around the magnet armature 10 and such housing is made generally in the form of a bell. It may be manufactured of synthetic resin or of a non-ferromagnetic metal or of an non-ferromagnetic metal alloy. The armature housing 17 bears two solenoid coils 18 and 19, which are arranged axially spaced from each other so that they are respectively arranged over the pole pieces 12. In this armature housing 17 the magnet armature 10 is arranged so that it may be moved axially and it is guided by the valve spool 13. An annular iron circuit return member 20 of ferromagnetic material is slipped over the magnet armature housing 17 and locked in position and furthermore fits into a suitable recess 21 in the valve housing 15.

In the outer end surface of the magnet armature housing 17 there is an inserted first magnetic field sensor 22. A second magnetic field sensor 23 is inserted between the solenoid coils 18 and 19 in the magnet armature housing 17 and, respectively, into the iron circuit return member 20. The two magnetic field sensors 22 and 23 are connected with signal amplifiers 24 and 25. Since the magnet armature 10 is permanently magnetic the magnetic field sensors 22 and 23 provide a simple way of detecting the stray field of the magnetic circuit and consequently of the position of the magnet armature 10.

The two solenoid coils 18 and 19 are operated respectively with an opposite effect, that is to say, they have respectively opposite current directions and practically constitute the air gap of the magnet system in conjunction with the iron circuit return member 20. In the pole pieces 12 the magnetic flux produced by the permanent magnet 11 is deflected. Dependent on the direction of the current through the two solenoid coils 18 and 19 there is an axial deflection to the left and, respectively, to the right, abutments, not illustrated, being provided if necessary. Owing to the two solenoid coils it is possible, despite the small size of the arrangement, to achieve force density even excelling that of conventional proportional magnets. The magnetic system is based on the reversal of the principle of a moving coil transducer as a

moving armature magnet system without any magnetic core.

The second working embodiment illustrated in figure 2 is similar to the first embodiment of the invention in structure so that like parts are denoted by like reference characters and are not described again. The essential difference resides in the fact that there is here only a single solenoid coil 18. The iron circuit return member 26, which is again substantially tubular, has, at the point of connection with the valve housing 15, an inwardly directed annular projection 27, which extends as far as a point near the magnet armature 10, that is to say as far as the right pole piece 12. There is a magnet armature housing 28 which has a tubular configuration and is connected integrally with the valve housing 15. In contradistinction to the first embodiment of the invention this magnet armature housing constitutes a guiding slide for the magnet armature 10.

In the case of this second working embodiment the magnet armature 10 and consequently the valve spool 13 is retained in the illustrated position in the non-excited condition of the solenoid coil 8 owing to the projection 27. The magnet armature 10 is drawn out of this position, dependent of the direction of current flow through the solenoid coil 18, to the left or to the right axially and after the current has been switched off it returns automatically into the illustrated position owing to the field of the permanent magnet 11, in which position the projection 27 on the magnetic pole abuts against the outer end of the magnet armature 10.

The third working embodiment illustrated in figure 3 again has a number of points of similarity with the second working embodiment so that like parts are denoted by like reference characters and are not described again. The most essential difference between this embodiment of the invention and the second one is that there is now a magnet armature 29, which is supplimented by the addition of a further permanent magnet 30 and of a further pole piece 12, which are not present in the second working embodiment. The two permanent magnets 11 and 30 are for this reason separated by a pole piece 12 and are oppositely

polarized. Furthermore a second iron circuit return member 31 having a projection 32 is mounted with bilateral symmetry of the iron circuit return member so that the two projections 27 and 32 extend to both sides of the solenoid coil 18 towards the magnet armature 29. Therefore two completely separate magnetic circuits are constituted, the first one consisting of the iron circuit return member 31, the left pole member 12 and the left permanent magnet 11 and the second one consists of the right iron circuit return member 26, the right pole piece 12 and the right permanent magnet 30. The middle pole piece 12 and the air gap through the solenoid coil 18 are shared by the two magnetic circuits. Owing to this arrangement an even higher servo force and an even higher return force are possible in the current-free neutral position, since now the two opposite outer poles of the magnet armature 29 tend to move back to the projections 27 and 32 in the non-excited condition.

In the illustrated working embodiment of figure 4 through 6 the magnet armature 10 is for simplification respectively illustrated without the valve element. However it may naturally be fitted with at least one valve spool, a valve plunger, a valve membrane or with some other known valve member. The same is also true for a valve housing, not illustrated. Furthermore like parts are denoted by like reference characters as in the previously described forms of the invention and are not described in the following again.

The working embodiment illustrated in figure 4 relates to an arrangement, in which the magnet armature 10 is held centered by the two solenoid coils in the non-excited condition. The two solenoid coils 18 and 19 are again, as in the first working embodiment, arranged over the two pole pieces and are retained in position by means of an essentially tubular magnet armature housing 33. An iron circuit return member 34 has two annular projections 35 and 36, which extend radially outwards, and which are arranged over the solenoid coils 18 and 19 and for this reason are again directed towards the pole pieces 12. The magnet armature housing 33 occupies the intermediate space between the projections 35 and

36 and partly the intermediate space between the solenoid coils 18 and 19. This arrangement makes possible an extremely short design but nevertheless a powerful servo force owing to the two magnet spools 18 and 19 and a satisfactory action owing to the two projections 35 and 36 directed towards the outer poles.

In the fifth working embodiment illustrated in figure 5 the magnet armature 10 has a non-centered neutral position. This means that the iron circuit return member 26 is designed in accordance with the second working embodiment, the one projection 27 pointing towards the left end pole of the magnet armature 10. Furthermore two solenoid coils 18 and 19 in accordance with the first embodiment of the invention are arranged in a tubular magnet armature housing 37.

In the sixth working embodiment illustrated in figure 6 an iron circuit return member 38 is constituted by a cylindrical housing, in which a tubular magnet armature housing 39 is arranged, which bears the two solenoid coils 18 and 19. The magnet armature 10 for this reason has two neutral positions, namely the abutment position on the left end surface of the iron circuit return member 38 shaped like a housing and the abutment setting against the right end surface 41. In order to transfer the magnet armature 10 between the two neutral positions the two solenoid coils 18 and 19, which are oppositely polarized, are respectively supplied with opposite currents. Connection members running to valve members, not illustrated, may be arranged to run through central openings 42 in the two end surfaces 40 and 41 or it is possible for the openings themselves to be employed as valve openings.

It will be seen from the embodiments of the invention illustrated in figure 4 through 6 that a customized design of the permanent magnet circuit, and more particularly of the iron circuit return member, is possible to set the neutral positions of the magnet armature 10 in an extremely simple way in case of need in order to for example to provide for particular valve functions such as with means for biasing in the middle or center position, for fail safe or for pulse valve functions.

In the case of the seventh embodiment of the invention

illustrated in figure 7 a magnet armature 43 is itself designed in the form of a valve spool. Two annular permanent magnets 44 and 45 at the two outer ends of a connecting member 46 in this case constitute the outer flow controlling lands or collars. An annular sliding member 47 of synthetic resin or of a non-ferromagnetic material in this case forms a middle land. The two solenoid coils 18 and 19 are arranged at the outer end parts in a tubular magnet armature housing 48, whose length is equal to the length of the magnet armature 43, and the distance between the coils from each other is equal to the distance between the permanent magnets 44 and 45. An iron circuit return member 49, which is in the form of a housing and is ferromagnetic, surrounds the entire arrangement, the two axial end surfaces 50 and 51 again having central openings whose diameter corresponds to the diameter of the permanent magnets 44 and 45 so that the magnet armature 43 may be moved through these openings 52. The two end surfaces 50 and 51 are in this case in the form of separate parts, however the entire iron circuit return member 49 may also be an integral structure.

The two permanent magnets 44 and 45 constituting the outer lands of the spool are oppositely radially polarized and may be displaced through the two solenoid coils 18 and 19 out of the illustrated neutral position illustrated, there then being a return into the neutral position owing to the end surface 50 and 51 of the iron circuit return member 49 automatically.

The eighth embodiment of the invention illustrated in figure 8 is representative of an application of the arrangement in accordance with figure 5 so that like parts are denoted by like reference characters and are not described in the following again. The arrangement generally illustrated in figure 5 is placed in a valve housing 53 manufactured of non-ferromagnetic material, for example synthetic resin. The lower pole piece in engagement with the projection 27 is provided with a valve sealing member 54, which is fitted into this pole piece 12. The corresponding, lower end surface 55 of the valve housing 53 is provided in the center with a valve hole 57 and a valve seat 56. A lateral connection port 58 functions as an outlet or, respectively, inlet.

In the non-excited condition of the two solenoid coils 18 and 19 the valve sealing member 54 is in sealing engagement with a valve seat 56. It is only when current flows through the solenoid coils 18 and 19 that the magnet armature 10 is lifted clear of the valve seat 56 so that the valve is opened. The valve is consequently designed in the form of a normally closed valve. If the insert in accordance with figure 5 is turned around in the valve housing it will then be a question of a normally open valve. It is also possible for both end surfaces to be designed in the form of oppositely moving valves.

Claims.

1 A solenoid valve with at least one solenoid coil, in which a magnet armature, which is provided with a valve element, is guided so as to be able to move axially, and in which a moving armature system without a magnetic core is provided in the case of which the magnet armature is at least partly in the form of a permanent magnet.

2 The solenoid valve as claimed in claim 1, wherein the magnet armature is arranged for axial displacement in a non-ferromagnetic magnet armature housing, said housing bearing at least one solenoid coil.

3 The solenoid valve as claimed in claim 2, wherein the magnet armature housing is tubular and constitutes a sliding guide for the magnet armature and furthermore constitutes a prolongation of a valve housing, in which the valve element, which is rigidly connected with the magnet armature, is guided for sliding movement.

4 The solenoid valve as claimed in claim 2, wherein the valve element, which is able to be slidingly and axially moved in a valve housing with a guiding action, constitutes an axial guide for the magnet armature rigidly connected with the same.

5 The solenoid valve 4, wherein the valve housing is connected with the housing of the magnet armature or is manufactured integrally wit it.

6 The solenoid valve as claimed in any one of the preceding claims 1 through 5, wherein a ferromagnetic iron circuit return member is externally fitted around the housing of the magnet armature and the at least one solenoid coil.

7 The solenoid valve as claimed in claim 6, wherein the

iron circuit return member has at least one inwardly directed annular projection which in the condition free of current of the at least one solenoid coil is directed towards one end pole of the magnet armature and predetermines the neutral position of it.

8 The solenoid valve as claimed in claim 7, wherein the annular projection is arranged outside the at least one solenoid coil.

9 The solenoid valve as claimed in claim 8, wherein the magnet armature has two opposite polarized permanent magnets arranged axially in series and two annular projections on the two sides of the at least one solenoid coil are directed respectively towards the outer end pole of the two permanent magnets.

10 The solenoid valve as claimed in claim 8, wherein the valve housing receives the iron circuit return member, the at least solenoid coil, the housing of the magnet armature and the magnetic armature, the magnet armature has at one end surface at least a valve sealing member and the valve housing has a valve seat which in the current-free condition of the solenoid coil is in contact with the valve sealing member.

11 The solenoid valve as claimed in claim 10, wherein the annular projection is directed towards the end part having the valve sealing member, of the magnet armature or towards the opposite end part.

12 The solenoid valve as claimed in claim 10 or claim 11, wherein the valve sealing member is let into the magnet armature.

13 The solenoid valve as claimed in claim 7, wherein two annular projections are directed towards two solenoid coils and the two end poles of the magnet armature are arranged underneath the same in the current-free condition of the solenoid coils.

14 The solenoid valve as claimed in claim 8, wherein the iron circuit return member is designed in the form of a housing and two annular projections constitute the end surfaces of this housing.

15 The solenoid valve as claimed in claim 14, wherein two solenoid coils are arranged in this housing-like iron circuit return member with an alignment in the axial direction and spaced apart from each other.

16 The solenoid valve as claimed in claim 14 or claim 15, wherein the central openings constituted by the annular projections are adapted to function as valve openings for a valve element.

17 The solenoid valve as claimed in claim 14 or claim 15, wherein the magnet armature is designed in the form of a valve spool, on which at least one flow control land is designed in the form of a permanent magnet.

18 The solenoid valve as claimed in claim 17, wherein two such lands are constituted by permanent magnets, which in the current-free condition of two solenoid coils are arranged underneath the same.

19 The solenoid valve as claimed in claim 17 or claim 18, wherein the permanent magnets have an annular configuration.

20 The solenoid valve as claimed in any one of the preceding claims 17 through 19, wherein at least one further land is designed in the form of an annular sliding member.

21 The solenoid valve as claimed in any one of the preceding claims 1 through 16, wherein the permanent magnet in the magnet armature has a cylindrical form and at its two ends is provided with cylindrical ferromagnetic pole pieces.

22 The solenoid valve as claimed in claim 21, wherein a further, oppositely polarized permanent magnet is arranged in series and is provided with pole pieces.

23 The solenoid valve as claimed in claim 13 or 15, wherein the distance between the pole pieces is approximately equal to the distance between the two solenoid coils.

24 The solenoid valve as claimed in claim 1, comprising an axial and/or radial magnetic field sensor adapted to respond to the movement of the magnet armature.

25 The solenoid valve substantially as described in the specification with reference to figure 1 of the accompanying drawings.

26 The solenoid valve substantially as described in the specification with reference to figure 2 of the accompanying drawings.

27 The solenoid valve substantially as described in the specification with reference to figure 3 of the accompanying drawings.

28 The solenoid valve substantially as described in the specification with reference to figure 4 of the accompanying drawings.

29 The solenoid valve substantially as described in the specification with reference to figure 5 of the accompanying drawings.

30 The solenoid valve substantially as described in the specification with reference to figure 6 of the accompanying drawings.

31 The solenoid valve substantially as described in the specification with reference to figure 7 of the accompanying drawings.

32 The solenoid valve substantially as described in the specification with reference to figure 8 of the accompanying drawings.

33 Whilst endeavouring in the foregoing Specification to draw attention to those features of the invention believed to be of particular importance it should be understood that the Applicant claims protection in respect of any patentable feature or combination of features hereinbefore referred to and/or shown in the drawings whether or not particular emphasis has been placed thereon.

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